Publication of IPC-8497-1
“Cleaning Methods and Contamination Assessment for Optical Assembly” and Future Research Strategy

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OFC 2006
March 6, 06
Baseline research used for IPC-8497 “Cleaning Methods and Contamination Assessment for Optical Assembly”

Collaboration with the standards bodies

Development of IPC-8497 “Cleaning Methods and Contamination Assessment for Optical Assembly”

Future Research Strategy
  – iNEMI project “Fiber Connector End-Face Inspection” (progress review)
  – Future Plans
Past participants

- Tatiana Berdinskikh, N. Albeanu Celestica
- Jennifer Nguyen, Solectron
- Yves Pradieu, Solectron-Iphotonics
- Randy Manning, Tyco Electronics
- Dave Silmser/Heather Tkalec, Alcatel
- Tom Mitcheltree, Cisco Systems
- Thomas Ronan, Ingrid Levy, Aerotech
- Frank (Yi) Zhang, Avanex
- Denis Gignac, Nortel Networks
- Carla Gleason, ExceLight Communications Inc/ Sumitomo Electric
- Les Aseere, Sanmina
- Matt Brown, USCONEC
- Steve Lytle, Westover Scientific
- Susan Grant, Corning
- Arnaud Nicolas, FCI
- Mark Vogel, Trace Labs
- David Horat, Diamond
- Paul Mohr JDSU
Current participants

- Tatiana Berdinskikh, Celestica
- Jose Garcia, JDS Uniphase
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- Randy Manning, Tyco Electronics
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- Tom Mitcheltree, Cisco Systems
- Thomas Ronan, Aerotech
- Heather Tkalec, Alcatel
- Frank (Yi) Zhang, Avanex
- Denis Gignac, Nortel Networks
- Doug Wilson, PVI Systems
- Dr. Chip Kilmer, Sagitta
- Dr. Sun-Yuan Huang, Intel
- Carla Gleason, ExceLight Communications Inc/ Sumitomo Electric
- Harvey Stone, Microcare
- John Culbert, Megladon Mfg
- Yutaka Sadohara, Sumitomo Electric
The cleanliness of fiber optics connectors is recognized as an industry wide-problem;

- There was no industry-standard for cleanliness of fiber optics connectors in 2002;
- The cleaning and inspection processes of contaminated connectors affect manufacturing time and therefore increase test and product cost for high density port systems;
- The influence of scratches/particles/oil contamination on optical performance has not been previously investigated in detail
Fiber Optic Signal Performance Project

- Fiber Signal Performance Project: Feb, 02- Sep, 04
- Objectives:
  - Learn the effects that many anomalies have on the performance of a fiber optic signal
  - Identify the severity of optical signal loss due to the most common potential hazards found in supplier and internal manufacturing processes
- Benefits:
  - Develop an Industry Standard for cleanliness of fiber optics connectors.
  - Improve the cleaning process and prevent fiber endface contamination
Fiber Optic Signal Performance Project

- Scratches
- Particles
- Finger prints

- Polishing scratches
- Particles
- Oil contamination (finger prints)
Published by Journal of SMTA, 2003

- Launch cable & DUTs defects-free
- Launch cable defects-free, CUTs S/N D44 to D320 scratches applied to the caldding area, DUTs S/n D45 to D323 scratches applied to the fiber MFD
Particle is on the cladding layer

- IL-1550nm/1310nm (clean) = 0.24/0.25 dB;
- IL-1550nm/1310nm (contaminated) = 0.92/1.07 dB;
- RL-1550nm/1310nm (clean) = 57.3/55.5 dB;
- RL-1550/1310nm (contaminated) = 56.5 dB/55.6 dB
Critical parameters:

- Distance the particle from the core
- Size of the particle
- Type of the particle
- Hardness of the particle/thickness

IL=1550/1310 (contaminated)=0.14/0.15 dB
RL=1550/1310 (contam.)=59.6/58.5 dB
IL=1550/1310 (clean)=0.11/0.11 dB
RL=1550/1310 (clean)=58.6/56.8 dB

IL=1550/1310 (contaminated)=16.77/18.08 dB
RL=1550/1310 (contaminated)=20.3/20.8 dB
IL=1550/1310 (clean)=0.11/0.05 dB
RL=1550/1310 (clean)=58.0/57.6 dB
Oil Contamination

• Oil application resulted in significant changes of RL:
  • RL decreased from 56.3 dB to 43.6 dB (wavelength-1310nm) and from 57.2 dB to 45.1 dB (wavelength 1550 nm)
2005 Research

- **Contact Diameter**: 130μm < d < 250μm
- **Cladding**: 25μm < d < 120μm
- **Area near the core**: d < 25μm
- **Ferrule Diameter**: 250μm < d < 400μm
- **Epoxy Ring Zone**: 120μm < d < 130μm
Published by APEX 2005

T19-3WD-2M

25um Area contamination

Initial IL: 0.08dB
Initial RL: 53dB

3 x Standard Deviation of IL: 0.0213dB
3 x Standard Deviation of RL: 3.46dB

Failed
Statistical Data Analysis - 2005 data

Box-plot graph for the IL of the sample 57A: clean (57A clean) and contaminated, Subgroup 1 (57A IL 1) and Subgroup 2 (57A IL 2)
The Factors Affected on the Optical Performance

Delta IL vs Distance from Core

Distance From Core (micron)

Delta IL
Published by APEX 2004

Delta RL vs Distance From Core

Distance from Core (micron)

Delta RL
Connection/contact layer

\[ n_2, \text{High index layer due to polishing} \]

\[ RL(dB) = 10 \log \left[ 2R \left( 1 - \cos \left( \frac{4\pi n_1}{\lambda} d \right) \right) \right] \]

\[ R = \left( r_1^2 + r_2^2 + 2r_1 r_2 \cos \delta \right) \left( 1 + r_1^2 r_2^2 + 2r_1 r_2 \cos \delta \right) \]

\[ r_1 = \frac{n_0 - n_2}{n_0 + n_2}, \quad r_2 = \frac{n_2 - n_1}{n_2 + n_1}, \quad \delta = \frac{4\pi}{\lambda} n_2 h \]
Arizona dust contaminated connectors: estimated contamination layer thickness at 1550 nm

Particles trapped in between two endfaces result in air gap
• Contact diameter calculations for mated connector pairs
  – Minimum contact diameter 146 µm, 0.5 kgf, 5 mm end face radii
  – Maximum contact diameter 195 µm, 0.9 kgf, 30 mm end face radii
  – Estimated contact diameter range for test connectors, 156-185 µm
• Contact diameter equations
  – Ferrule end face deformation \( h \) at 0.5 kgf and 0.9 kgf contact force

\[
h_{0.5}(R) = 191.8 \cdot R^{-0.795} \quad \text{Contact Diameter equation}\]
\[
h_{0.9}(R) = 236.8 \cdot R^{-0.795}
\]

\[
d_{\text{contact}}(R_1, R_2) = \sqrt{2 \cdot h(R_1) \cdot R_1 - h(R_1)^2} + \sqrt{2 \cdot h(R_2) \cdot R_2 - h(R_2)^2}
\]
Sumitomo/ExceLight experiment for Receptacle Modules
Components of Variation

- Gage R&R
- Repeat
- Reprod
- Part-to-Part

Percent Contribution:
- Gage R&R: 100%
- Repeat: 50%
- Reprod: 0%
- Part-to-Part: %

Sample Range:
- R = 1.891
- UCL = 4.868
- LCL = 0

Sample Mean:
- X̄ = 37.43
- UCL = 39.37
- LCL = 35.50

Aoki Joe Kaneko

Published by Photonics North 2006 Conference

R Chart by Operator
- UCL = 4.968
- R = 1.891
- LCL = 0

X-bar Chart by Operator
- UCL = 39.37
- X̄ = 37.43
- LCL = 35.50

OQL by Sample

OQL by Operator

Operator * Sample Interaction

Operator
- Aoki
- Joe
- Kaneko

Average
- Sample
- Range

Connect with and Strengthen Your Supply Chain
Occluded Area Images - More Detail

OFC 2006

Labeled Detected Particles
(color coded by annular ring)

Labeled with rings
The Delta IL for the worse-case defects and scratches based on inspection criteria is less than 0.03 dB
Publications

- “Cleaning Standard for Fiber Optics Connectors Promises to Save Time and Money”, Photonics Spectra, June 2004, pp.66-68
- “Keeping it clean: A cleanliness specification for single-mode connectors”, Connector Specifier, Aug, 05, pp.8-10.
- “Contamination Influence on Receptacle Type Optical Data Links”, Photonics North, 2005, Toronto, Canada, Sep, 05.
- “Development of Cleanliness Specifications for 2.5 mm and 1.25 mm ferrules Single-Mode Connectors” – Proceedings of OFC/NFOEC, Anaheim, California, Mar 5-10, 06

8 Papers published by the Project Team
Collaboration with TIA, IEC and IPC

- The Project is collaborating with International Electrotechnical Committee (IEC), Telecommunications Industry Association (TIA) and IPC to develop a cleanliness standard.

**iNEMI presentations:**

- OMI conference, Ottawa, Apr-29-May 1, 2003
- IEC meeting, Montreal, Quebec, Canada, Oct 6-13, 2003 (presented by T. Berdinskikh, Celestica)
- APEX2004, Anaheim, California, Feb 19-Feb 26, 2004
- IEC meeting, Locarno, Switzerland, Apr, 04 (presented by T. Mitcheltree, Cisco)
- IEC meeting, Warsaw, Poland, Sep, 04 (presented by R. Manning, Tyco)
- A draft of IPC-8497-01 “Cleaning Methods and Contamination Assessment for Optical Assembly” has been submitted to IPC (June, 04)
- APEX2005, Anaheim, California, Feb, 05
- IEC meeting, Charlotte, NC, Apr, 05 (presented by R. Manning, Tyco)
- OFC2006, Anaheim, California, Feb, 06
Our Objective:
• Update the criteria in IEC doc “61300-3-35: Basic test and measurement procedures” based on quantitative data
• Harmonize our recommendations across all vendors/CMs/OEMs to achieve a true international standard

Summary from Montreal IEC-2003:
• Scratches and particles within 25um diameter definitely affect SMF performance
• Scratches outside of 25um definitely do NOT affect SMF performance
• Further investigation needed on particles outside 25um
Summary from IEC meeting, Locarno, Apr, 04, presented by the iNEMI team

- Small Carbon particles on the ferrule did not show any performance degradation
- Small Carbon particles on the cladding outside the 25 um zone do not significantly impact performance
  - e.g., Up to 17 particles on cladding outside of 25um…no impact
- Contamination particles can prevent direct physical contact creating an air gap between two endfaces
- Further investigation is needed for contamination located at cladding and ferrule areas
- Investigate the influence on the Arizona dust particles on the optical signal performance
IPC-8497 development

- Project Team made the initial contacts with IEC, TIA and IPC representatives at OMI conference, Ottawa, May, 2003
- The first-face-to-face meeting of the project team on the standard development was held at Celestica and Cisco facilities in Salem, Jun, 04.
- The final document was submitted to the IPC review in July, 05
- The IPC-8497-1 “Cleaning Methods and Contamination Assessment of Optical Assembly” was published by IPC in Feb, 2006.
- The acceptance of an industry standard for SM connectors will result in significant cost savings to fiber optics industry due to the elimination of insufficient cleaning and over cleaning and the reduction of contaminated non-conformance material.
1. Scope
2. Applicable documents
3. Terms and Definitions
4. Cleaning Specification
5. Contamination
6. Inspection Equipment
7. Cleaning Methods
8. End-caps
9. Performance testing
10. Electrostatic Charge Effect (ESD) and Connector Cleanliness
11. The Influence of Scratches/Contamination on Optical Signal Performance
Scope of IPC-8497

- The scope of the specification is to describe the methods of inspecting and cleaning all optical interfaces so their interconnectivity does not result in loss of optical signal. It also describes methods of contamination prevention.
- The target audience for this standard are Manufacturing Operators, Manufacturing Process Engineers, Quality Engineers and Field System Installers.
## Inspection Criteria for SMF Pigtail and Patchcord Connectors

<table>
<thead>
<tr>
<th>Zone/Description</th>
<th>Diameter</th>
<th>Defects (diameter)</th>
<th>Scratches (width)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a — Core Zone</td>
<td>0 to 25 microns</td>
<td>none</td>
<td>none</td>
</tr>
<tr>
<td>1b — Cladding Zone</td>
<td>25 to 120 microns</td>
<td>any &lt; 2 microns 5 from 2 - 5 microns none &gt; 5 microns</td>
<td>none &gt; 3 microns</td>
</tr>
<tr>
<td>Adhesive Zone</td>
<td>120 to 130 microns</td>
<td>any</td>
<td>any</td>
</tr>
<tr>
<td>2 — Contact Zone</td>
<td>130 to 250 microns</td>
<td>none &gt; 10 microns</td>
<td>any</td>
</tr>
</tbody>
</table>
Objective:

This project is developing requirements for allowable surface defects, such as scratches, pits, and contamination. Based on experimental data and the results of mathematical modeling, the group plans to define the zone criteria and pass/fail visual requirements for polished connectors, single mode fiber.
Phase 1

- **PHASE 1 (Completed)**
- Fiber Optic Connector End-face Anomaly Assessment for SM fiber
- The losses, (IL and RL), which occurs on SC, FC, LC, MU connectors due to contamination with Arizona road dust and polishing scratches will be examined.
- The DOE (Design of experiment) that was used in the Fiber Optic Signal Performance Project for singlemode SC connectors will be used for this phase of the project. (Ref: Avanex experiments, Optical Signal Performance project)
- Statistical data analysis will be performed.
- Results for the influence of scratches and Arizona road dust for SC connectors will be compared with the results from the other types of connectors (SC, FC, LC, MU)
- Mathematical modeling for the RL results will be provided.
- Inspection criteria for SM connectors will be finalized.
• PHASE 2- In Progress
• Fiber Optic Connector End-face Anomaly Assessment for MM fiber
• The loss (IL, RL, and BERT) realized by MM applications due to fiber optic connector end-face anomalies (polishing scratches and Arizona dust contamination) will be assessed.
• The DOE (Design of experiment) that was used in the Fiber Optic Signal Performance Project for singlemode SC connectors will be used for this phase of the project. (Ref: Avanex experiments, Optical Signal Performance project)
• Perform Gage R & R study
• Statistical data analysis will be performed.
• Inspection criteria for MM connectors will be developed
Phase 3

- PHASE 3- In Progress (Sumitomo/ExceLight initiatives)
- Fiber Optic Connector End-face Anomaly Assessment for Receptacle Modules
- Data rates to be studied will be chosen (OC-48, OC-192, etc.)
- Provide Gage R & R study for test and measurement equipment
- A method for application of anomalies will be developed
- The influence of the dust and scratches on the optical performance of receptacle modules will be investigated
- Statistical data analysis will be performed
- Critical factors such as particle size, distance from the core, type of particles, will be identified
- The correlation between measurements, (RL, BERT and other tests yet to be determined), and images of the connector end-face will be calculated.
- Criteria for cleanliness of receptacle modules will be developed
Phase 4

- **PHASE 4- In progress**
- Collaboration with standards bodies
- A roadmap for the collaboration with the TIA, IPC, IEC will be developed.
  - Collaboration with the IPC will be on standard IPC-8794-01: "Cleaning methods and contamination assessment for optical assembly" (completed)
  - A recommendation to update the IEC doc “61300-3-35: Basic test and measurement procedures” based on quantitative data will be put forth.
- Recommendations will be harmonized across all vendors, EMS providers, and OEMs to achieve a true international standard.
PHASE 5- In Progress

Improving the cleaning process and prevention of contamination

To understand the root causes of contamination and develop the strategy to prevent or minimize the risk of contamination in the manufacturing environment

- Compare different cleaning materials with improved ESD capability to prevent connector charging during the cleaning process
- Contamination caused by the dust cap
- Standardization of the dust cap: developing a recommendation on materials and design
- Investigation of ESD effects for mated optic connectors
Phase 6

- The following topics require further research to determine if other consortia or standards bodies have not already performed the work.
- Fiber Optic Connector End-face Anomaly Assessment for SM APC
- Estimate of the time & effort needed to investigate SM APC.
- Fiber Optic Connector End-face Anomaly Assessment for MT ferrule
- Estimate of the time & effort needed to investigate SM MT ferrule
Future Plans

• Further research will focus on the development of a cleanliness specification for MM connectors and receptacle modules.
• Open discussion
Back up Slides
Core is blocked

- **IL-1550nm/1310nm(clean)** = 0.39/0.51 dB
- **IL-1550nm/1310nm(contaminated)** = 2.88/3.61 dB
- **RL-1550nm/1310nm(clean)** = 56.2/54.6 dB;
- **RL-1550nm/1310nm(contaminated)** = 37.1/34.5 dB
Particles on Ferrule only

- IL-1550nm/1310nm (clean)=0.19 dB/0.21 dB
- IL-1550 nm/1310nm (contaminated)=0.21 dB/0.21 dB
- RL-1550nm/1310nm (clean)=55.7 dB/54.5 dB
- RL -1550nm/1310nm (contaminated)=55.6 dB/54.5 dB
Carbon Particles on Cladding / Ferrule Area
Distances calculated with VisionGauge software

IL-1550nm/1310 nm (clean connector) = 0.05/0.09 dB,
IL-1550nm/1310 nm (contaminated connector) = 0.04/0.05 dB,
RL-1550/1310 nm (clean connector) = 58.2/57.4 dB,
RL-1550nm/1310 nm (contaminated connector) = 57.3/56.4 dB
Occluded Area Graphs

Data for connector LC07

Incremental occluded area vs radius
Cumulative occluded area vs radius

For comparison, core exclusion zone area is about 491 µm²
Ideal SMF SC UPC ceramic-ferrule endface